Distributed Sensor Networks with Collective Computation (DSN-CC) for *In-Situ* Sensing

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Classical Sensor Network vs. DSN-CC Approach

Classical Advantages

- Little/no processing at the sensor.
- Simple sensor and network design.
- Raw data available at a central processing station (CPS).

DSN-CC Advantages

- Central processor absent.
- Tolerant to single-point failures.
- Easier scale-up in sensor number.

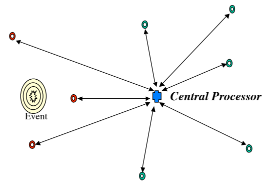

Figure 1: Classical Sensor Network Topology.

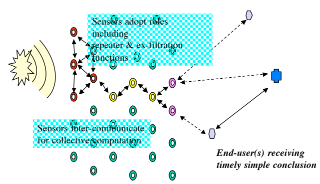

Figure 2: Distributed Sensor Network with Collective Computation Approach.

Theoretic Prediction of Energy and Time

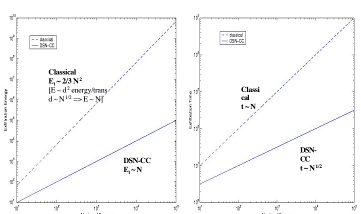

Figure 3: Energy and time for exfiltration scaling with sensor network size for Classical and DSN-CC approaches.

Commercial Wireless Sensor Mesh Networks

- Self-organizing/self-healing.
- Spread spectrum/ multi-hopping.
- Little processing power.

Figure 4: COTS Wireless Mesh Networks from Crossbow Technology, Millenial Net and Ember Corporation.

Source Detection Application

- Radioactive source detection.
- Heterogeneous network approach.
- *Motes* detect vehicle presence.
- *PDA's* record and evaluate information from radiation detectors.

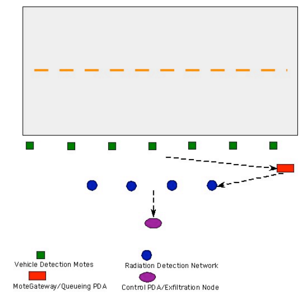

Figure 6: Source detection network design.

Figure 7: Deployed vehicle detection mote network.

Bayesian Radiation Detection Methods

- Use counts collected in the network in successive intervals and collected background statistics.
- Integrate over possible trajectories.
- Results indicate the probability a source is present.

$$\frac{\int_0^{h_m}\int_0^{v_m}\int_{-x_m}^{x_m}\Pr\left(c_{11},c_{12},\ldots,c_{\Phi\Theta}\mid a,h,v,x\right)dhdvdx}{\int_0^{h_m}\int_0^{v_m}\int_{-X_m}^{X_m}\Pr\left(c_{11},c_{12},\ldots,c_{\Phi\Theta}\mid a,h,v,x\right)dhdvdx}$$

- In simulation:
  - Background rate = 10 cnts/sec.
  - Sensors placed in a rectangle 10 m x 600 m.
  - Source velocities between 20 and 60 km/hr and constant.

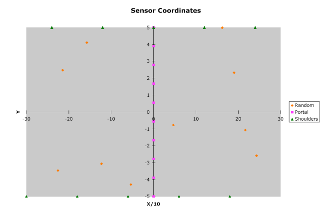

Figure 8: Sensor configurations modeled using Bayesian techniques.

Amplitude	False Negative Rate	False Positive Rate
1	0.5	0.48
10	0.42	0.28
100	0.17	0.04
1000	0.002	0.001

Table 1: Simulation detection results for a network of 10 sensors deployed in a random arrangement.

Amplitude	False Negative Rate	False Positive Rate
1	0.46	0.5
10	0.16	0.04
100	0.00	0.00
1000	*	*

Table 2: Simulation detection results for a network of 100 sensors deployed in a random arrangement.

Bayesian Estimation of Radioactive-Source Parameters

$$\left\langle a^i h^j v^k\right\rangle = \frac{\int_0^{a_m}\int_0^{h_m}\int_0^{v_m} a^i h^j v^k \Pr\left(c_{11},c_{12},\ldots,c_{\Phi\Theta}\mid a,h,v\right)dadhdv}{\int_0^{a_m}\int_0^{h_m}\int_0^{v_m}\Pr\left(c_{11},c_{12},\ldots,c_{\Phi\Theta}\mid a,h,v\right)dadhdv}$$

- Assume these are independent Poisson random variables.
- <a> = source amplitude
- <h> = height of the trajectory above the line of equally-spaced sensors
- <v> = source velocity
- The estimates are characterized by a mean and standard deviation plotted in the following figures.
- Details in Nemzek *et al.*, Distributed Sensor Networks for Detection of Mobile Radioactive Sources, *IEEE Transactions on Nuclear Science*, **51**, in press (2004).

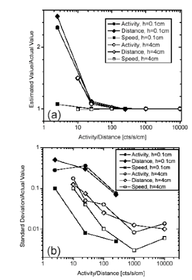

Fig. 5 Noise limitations (β=7cts/s, d=4cm, v=1cm/s, number of sensors=10, τ=2s, number of time points=21, h=0.1cm or 4cm, as indicated in legend). (a): <a>/a, <h>/h, and <v>/v, plotted as a function of a/h. The average first moments are plotted, after five realizations of Poisson random variables with the same expectations—for each time interval and each sensor. (b) : The standard deviations of the first moments over the five realizations are plotted, after normalizing by the parameter value, as in 5a.

Conclusions

- This work demonstrates the capabilities of distributed sensor networks for the detection of mobile radioactive sources.
- These networks employ heterogeneous wireless nodes and heterogeneous sensors.
- Simulation and modeling guide system development and implementations.
- Bayesian methods are practical for source detection, but further adaptation is required.